Review Paper on Reaction of Alkaline Solution in GEO-Polymer Concrete

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Abstract— Geopolymer is a class of aluminosilicate binding materials synthesized by thermal activation of solid aluminosilicate base materials such as fly ash, metakaolin, GGBS etc., with an alkali metal hydroxide and silicate solution. The geopolymer was activated with sodium hydroxide, sodium silicate and heat. This paper presents the experimental investigation done on the variation of alkaline solution on mechanical properties of geopolymer concrete. The grades chosen for the investigation were M-30, M-40, M-50 and M-60, the mixes were designed for 8 molarity. The alkaline solution used for present study was the combination of sodium silicate and sodium hydroxide solution with the varying ratio of 2, 2.50, 3 and 3.50. The test specimens were 150x150x150 mm cubes and 100x200 mm cylinders heat-cured at 60°C in an oven. The results revealed that the workable flow of geopolymer concrete was in the range of 85 to 145 and was dependent on the ratio by mass of sodium silicate and sodium hydroxide solution. The freshly prepared geopolymer mixes were cohesive and their workability increased with the increase in the ratio of alkaline solution. The strength of geopolymer concrete can be improved by decreasing the water/binding and aggregate/binding ratios. The curing period improves the polymerization process resulting in higher compressive strength. The geopolymer concrete do not have any Portland cement, they can be considered as less energy interactive. It utilizes the industrial wastes such as fly ash for producing the binding system in concrete. The obtained compressive strength and split tensile strength were in the range of 20.64 – 60 N/mm2 and 3 – 4.9 N/mm2. The optimum dosage for alkaline solution can be considered as 2.5, because for this ratio the GPC specimens of any grade produced maximum strength in compression and tension.

Keywords*: Geopolymer concrete, F- fly ash, Molarity, Sodium silicate, Sodium hydroxide.*

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I. INTRODUCTION

Geopolymers are inorganic polymeric binding materials, firstly developed by Joseph Davidovits in 1970s. Geopolymerisation involves a chemical reaction between solid alumino-silicate oxides and alkali metal silicate solutions under highly alkaline conditions yielding amorphous to semi-crystalline three-dimensional polymeric structures, which consist of Si-O-Al bonds. The Geopolymerisation reaction is exothermic and takes place under atmospheric pressure at temperatures below 100°C. The exact mechanism by which geopolymer setting and hardening occurs is not yet fully understood. However, the most proposed mechanisms for the Geopolymerisation includes the following four stages that proceed in parallel and thus, it is impossible to be distinguished: (i) dissolution of Si and Al from the solid aluminosilicate materials in the strongly alkaline aqueous solution, (ii) formation of oligomers species (geopolymers precursors) consisting of polymeric bonds of Si-O-Si and/or Si-O-Al type, (iii) polycondensation of the oligomers to form a three-dimensional aluminosilicate framework (Geopolymeric framework) and (iv) bonding of the unreacted solid particles and filler materials into the Geopolymeric framework and hardening of the whole system into a final solid polymeric structure. Fly ash, which is rich in silica and alumina, has full potential to use as one of the source material for Geopolymer binder. It is the main solid waste generated from the coal combustion in the power stations. Since the Worldwide electric power industry relies heavily on the use of coal as a primary energy source; enormous quantities of fly ash are generated every year[1]. According to 2000 estimation, the annual global fly ash production was more than 600 million tons. In the India, the annual production of fly ash is approximately 110 million ton and its generation is likely to reach 170 million tons by 2010. Presently, as per the Indian Ministry of Environment and Forest figures, only 20% to 30% of fly ash is used in manufacturing cements, construction, concrete, block and tiles and some disposed off in landfills and embankments, but a huge amount of fly ash is unutilized which causes several environmental problems of the air, soils and surface and ground-water pollution[2]. The utilization of fly ash in the development of geopolymeric materials for construction purposes has been and continues to be subject of many research studies. Recent works on the Geopolymerisation of fly ash, reported production of geopolymeric materials with high mechanical strength, low density, less water absorption, negligible shrinkage and significant fire and chemical resistance. Due to these properties, Geopolymeric materials are viewed as an alternative to Portland cement for certain industrial applications in the areas of construction, transportation, road building, aerospace, mining and metallurgy

The main reaction product of alkali-activated fly ash is an alkaline silico-aluminate gel . The OHP-P ion acts as a reaction catalyst during the activation process and the alkaline metal (NaP+P) acts as a structure-forming element. [1].The structure of the pre-zeolite gel contains Si and Al tetrahedral randomly distributed along the polymeric chains that are cross-linked so as to provide cavities of sufficient size to accommodate the charge balancing hydrated sodium ions.

A. GEOPOLYMERS

The chemical composition of the geopolymer material is similar to natural zeolite materials, but the microstructure is amorphous. The polymerization process involves a substantially fast chemical reaction under alkaline condition on Si-Al minerals that result in a three dimensional polymeric chain and ring structure consisting of Si-O-Al- O bonds, as follows:

Mn [-(SiO2) z–AlO2] n. wH2O

where, M = the alkaline element, indicates the presence of a bond, n is the degree of polycondensation or polymerization, z is1,2,3 or higher up to 32 [2]. The strength of geopolymer depends on the nature of source materials. Geopolymers made from calcined source materials, such as metakaolin (calcined kaolin), fly-ash, slag etc., yield higher compressive strength when compared to those synthesized from non-calcined materials, such as kaolin clay. A combination of sodium or potassium silicate and sodium or potassium hydroxide has been widely used as the alkaline activator. Since heat is a reaction accelerator, curing of a fresh geopolymer is carried out mostly at an elevated temperature.

II. EXPERIMENTAL WORK

A. MATERIALS

1. FLY ASH

Typical Class-F fly ash from Kolaghat Thermal Power Station located near Kolkata was used in the present study. The chemical composition of fly ash determined by XRF analysis is given in Table-1

CHEMICAL COMPOSITION	FLYASH(%MASS)
$Si0_2$	57.79
Al_20_3	20.18
Fe_20_3	7.04
$Ti0_2$	1.03
Ca0	2.97
MgO	1.98
P_20_5	0.26
$S0_3$	0.84
Alkaline	3.69
LOI	4.22

The calcium oxide content of the fly ash is less than 10% hence; it can be classified as Class-F fly ash, according to ASTM standard C6128-03. (Or siliceous pulverised fuel ash conforming to IS 3812(Part-I)-2003 specifications). About 90% of particles were smaller than 45 micron. The Blaine specific surface was 380Mp 2 P/kg. According to the XRD diffractograms of fly ash shown in Figure-1, the major crystalline constituents are quartz (SiOB2B), mullite and magnetite. The fly ash is also constituted of an X-ray amorphous phase indicated by the broad hump registered between 2θ =20° and 30°. The SEM micrograph of original fly ash also shows that fly ash particles are spherical in shape of different diameters.

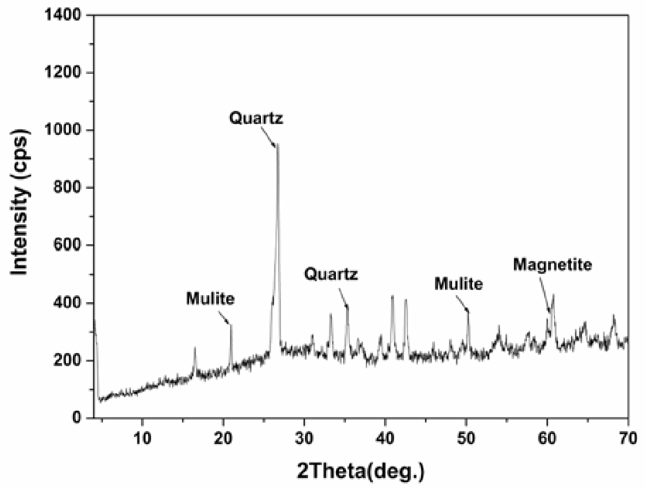

Figure-1. X-ray diffractograms of fly ash.

2. ALKALINE ACTIVATOR

The alkaline activator liquid used was a combination of sodium silicate solution and sodium hydroxide. The sodium silicate solution (NaB2BO= 14.7%, SiOB2B =29.4% and 55.9% water) with silicate modulus of 2.0 and a bulk density of 1390 kg/mP 3Pand an analytical grade sodium hydroxide in pellets form (Merck Chemicals Ltd., NaOH with 98% purity) was used to adjust the composition of activating solution[3]. To avoid effects of unknown contaminants in laboratory tap water, the distilled water was used for preparing activating solutions. A commercially available high range water reducing admixture (HRWRA) was used to improve workability of fresh mix. The activator solution was prepared at least one day prior to its use in specimen casting.

3. FINE AGGREGATE

The fine aggregate was river sand obtained from local source. The specific gravity of sand was 2.54 and fineness modulus of the sand was 2.65. As per IS 383- 1976, the particle size distribution of sand shows that it is in zone II[2]. The sand was made saturated surface dry (SSD) before using in geopolymer mix to avoid water absorption from activator solution.

III. PREPARATION, CASTING AND CURING OF GEOPOLYMER CONCRETE

The alkaline activator solution used in GPC mixes was a combination of sodium hydroxide solution, sodium hydroxide pellets and distilled water. The role of AAS is to dissolve the reactive portion of source materials Si and Al present in fly ash and provide a high alkaline liquid medium for condensation polymerization reaction. To prepare sodium hydroxide solution of 8 molarity (8M), 320 g of sodium hydroxide flakes was dissolved in water. The mass of NaOH solids in a solution will vary depending on the concentration of the solution expressed in terms of molar, M[4]. The pellets of NaOH are dissolved in one liter of water for the required concentration. When sodium hydroxide and sodium silicate solutions mixed together polymerization will take place liberating large amount of heat, which indicates that the alkaline liquid must be used after 24 hours as binding agent.

FIGURE-2 MIXING OF ALKALINE SOLUTION

GPC can be manufactured by adopting the conventional techniques used in the manufacture of Portland cement concrete. In the laboratory, the fly ash and the aggregates were first mixed together dry on pan for about three minutes. The liquid component of the mixture is then added to the dry materials and the mixing continued usually for another four minutes [Fig. 1 and 2]. The addition of sodium silicate is to enhance the process of geopolymerization [12]. For the present study, concentration of NaOH solution is taken as 8M with varying ratio of Na_2SiO_3 / NaOH as 2, 2.5, 3 and 3.5 for all the grades of GPC mixes. The workability of the fresh concrete was measured by means of conventional slump test [Fig. 4]. In order to improve the workability, superplasticiser Conplast SP-430 with a dosage of 1.5% by mass of the fly ash was added to the mixture. Extra water (other than the water used for the preparation of alkaline solutions) and dosage of super plasticizer was added to the mix according to the mix design details[5]. The fly ash and alkaline activator were mixed together in the mixer until homogeneous pate was obtained. This mixing process can be handled within 5 minutes for each mixture with different ratios of alkaline solution. Heat curing of GPC is generally recommended, both curing time and curing temperature influence the compressive strength of GPC [6]. After casting the specimens, they were kept in rest period for two days and then they were demoulded. The demoulded specimens were kept at 60°C for 24 hours in an oven.. The demoulded procedure is similar to that of routine conventional concrete.

IV. RESULTS AND DISCUSSIONS

A. WORKABILITY

Fresh GPC mixes were found to be highly viscous and cohesive with medium to high slump. The workability of the geopolymer concrete decreases with increase in the grade of the concrete as presented in Fig. 5, this is because of the decrease in the ratio of water to geopolymer solids. The ratio of alkaline solution increases the slump value for any grade of GPC, this is due to the fact that there will be more amount of sodium silicate solution and the water present in the fly ash will be released into the mixture during the mixing[5]. An increase in sodium silicate concentration thus reduces the flow of GPC. Hence we can say that as the grade of the concrete increases, the mix becomes stiffer decreasing the workability, which result in strength reduction. The effect of ratio of sodium hydroxide to sodium silicate solution by mass on the compressive strength of concrete can be seen by comparing the results. For these grades the concentration of sodium silicate solution (in terms of molarity), the water content, the fly ash content and the condition of curing were kept constant. The ratio was varied from 2 to 3.5, in the increment of 0.5. the average maximum strength was obtained when the ratio was 2.5.

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FIGURE -3 MIXING OF GPC

B.COMPRESSION STRENGTH

The compressive strength is one of the most noteworthy properties of hardened concrete and is considered as the characteristic material value for the classification of concrete. The chemical reaction of the geopolymer gel is due to substantially fast polymerization process, the compressive strength do not vary with the age of concrete. This observation is in contrast to the well-known behavior of OPC concrete, which undergoes hydration process and hence gains strength over the time.[5] The cube specimens of the GPC mixes, when tested under compression, generally failed in the 'pyramidal frustum' form, similar to the regular Portland cement concrete cubes. It is clear from the test results that maximum strength was observed for the alkaline ratio of 2.5, this variation was true for any grade of concrete. The strength increased with the increase of NaOH concentration mainly through the leaching out of silica and alumina .

C.SPLIT TENSILE STRENGTH

The split tensile strength of geopolymer concrete is only a fraction of compressive strength, as in case of Ordinary Portland cement concrete. The split tensile strength increases up to ratio of 2.5, then suddenly the results goes on decreasing for alkaline ratios of 3 and 3.5, hence we can conclude that the split tensile strength results are in match with cube compressive strength[6]

D.ACID RESISTANCE

The sulfuric acid resistance of geopolymer concrete is evaluated. To perform the acid attack in the present investigation immersion techniques is adopted. After casting and curing, cylinders of size 100mm diameter and 200mm height specimens are immersed in H solution.The concentration of sulfuric acid solution is 0.5%, 1% and 2%. The pH value of distilled water is 6.17 and it is dropped as 5.90, 5.77 and 5.54 respectively in 0.5%, 1% and 2% acid concentration . The evaluation is conducted after 90days from the date of immersion .solution is kept at room temperature and the solution is stirred regularly. The solution is replaced at regular intervals to maintain concentration of solution throughout the test period [5]. The weight of geopolymer concrete decreases when the acid concentration increases and the same effect is reflected after 90 days immersion in acid. The weight of GPC specimen after immersion will be decreased.

E.SULPHATE RESISTANCE

The sulphate is present in the soil in many forms such as calcium, sodium, potassium and magnesium .The sulphate attack is a common occurrence in natural and industrial situations. Sodium sulphate salt of 99% purity is taken as 5%[2]. The cylinders are prepared with different concentration of 12 M, and 14 Mole of NaOH. The concentrated sodium sulphate salt of 550g is dissolved in 11 litter of water. The pH value of $Na2SO4$ solution is maintained as 7.15The increase of weight and decrease of compressive strength of different concentration of NaOH used in GPC specimens[4].

TABLE-2 WEIGHT CHANGE IN CHEMICAL TEST

MOLE SOLUTION	INITIAL OF SPECIMENS WEIGHT(gms)	AFTER 90 DAYS OF SPECIMENSWEIGHT (gms)
8M	3770	3989
10M	3670	3927
12M	3660	3806

TABLE-3 COMPRESSION STRENGTH AFTER CHEMICAL ATTACK

MOLE SOLUTION	INITIAL OF SPECIMENS COMPRESSION STRENGTH(N/mm^2)	AFTER 90 DAYS OF SPECIMEN COMPRESSION STRENGTH(N/mm^2)
8M	28.0	24.9
10M	26.5	25.9
12M	33.5	30.6

V. CONCLUSIONS

Based on the experimental investigations done the following conclusions can be drawn:

1. For any grade of GPC, as ratio of alkaline solution increases, the workability of mix goes on increasing.
2. 2.The study showed that the strength of geopolymer concrete can be improved by decreasing the water/binding and aggregate/binding ratios. It was observed that water influences the geopolymerization process and the hardening of concrete. Inclusion of increased binder content enhances the geoplymerization and affects the final strength.
3. The optimum dosage for alkaline solution, which is used a geopolymer binder can be considered as 2.5, because for this ratio, the GPC specimens of any grade produced maximum strength results with compression and tension.
4. The fly ash can be used to produce geopolymeric binder phase which can bind the aggregate systems consisting of sand and coarse aggregate to form geopolymer concrete (GPC). Therefore these concretes can be considered as eco-friendly materials.

VI. REFERENCE

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